Application of a coupled SWAT-BATHTUB model to evaluate phosphorus critical source areas and land management alternatives on the water quality of Lake Prespa, Macedonia

*Presented at the 2015 international SWAT conference, Sardinia, Italy*
Presentation Outline

Study area

Study objectives

SWAT model:
  • Development
  • Calibration and Validation

BATHTUB model
  • Background and development
  • Simulation results

Phosphorus critical source area (CSA) analysis

Alternative management practices (preliminary results)

Conclusions and next steps
Study Area: Lake Prespa

You are here!

International:
- Macedonia
- Albania
- Greece

Watershed area:
- Land: 1,054 km²
- Lake: 305 km²

Elevation:
- Min: 823 m
- Max: 2,420 m
Study Area: Lake Water Quality Status

Based on 2014 monitoring data, Prespa lake can be classified as:

- **eutrophic** based on TP
- **mesotrophic** based on secchi depth and Chl-A concentrations
Study Objectives

Develop a coupled SWAT/BATHTUB model

Identify phosphorus CSAs

Develop and evaluate alternative management practices

Determine impact of alternatives on lake water quality

Compile knowledge gained into a management tool for UNDP to guide future activities in the watershed
SWAT Development: Subbasin/HRU Delineation Data

UNDP (20 m) and ASTER (30 m) stitched to produce 20 m DEM

CORINE 2000/2006 (100 m) and vector orchard boundaries stitched and resampled to produce 20 m land use

ESDB (1 km), FAO (10 km) and 32 UNDP field samples integrated to produce soils data
SWAT Development: Subbasin/HRU Delineation Results

Land Use:
- 80% undeveloped
- 19% agriculture
- 1% developed

Soils: 48 soils classes, hydro group C dominant

Slope: 5 classes
- 0 – 3%: 10%
- 3 – 15%: 21%
- 15 – 25%: 17%
- 25 – 50%: 38%
- > 50%: 13%

HRU Delineation: No thresholds applied
- 126 subbasins
- 5,061 HRUs total
SWAT Model Development: Weather and Agronomy

Daily precipitation and temperature:
- NCEP CFSR, 1979-2013, 4 stations
- UNDP 2006-2014, 2 stations

Lapse rates generated from long term isohyetal and temperature maps

Agronomic management schedules:
- Apples, wheat, potato (Macedonia)
- Corn, lima bean (Greece, Albania)
- Timing and frequency of planting, harvesting, tillage, irrigation, and fertilizer applications derived by local agronomist.
**SWAT Calibration: Streamflow data**

- Brajcinska River at Brajcino
- Golema River near Resen (estimated)

Model warmup: 1979-1982

Calibration: 1997-2010

Validation: 1983 – 1996

Model performance evaluated based on guidelines by Moriasi et al. (2007)

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Based on performance evaluation criteria, PBIAS is “very good”, NSE is “satisfactory”, and RSR is “good”
SWAT Validation: Example Streamflow Results

Based on performance evaluation criteria, PBIAS is “very good”, NSE and RSR are “satisfactory”
SWAT Calibration: Water Quality Data

Monitoring data: 8 sites, 12/2013-12/2014 (continuing in 2015)

Between 6 and 11 samples per site

Majority of samples during low flows

Calibration Strategy:
  • Qualitative comparison of observed concentration distributions with simulated distributions (same flow rate range)
  • Watershed-level calibration, uniform parameter adjustments
Sediment and TP simulations very close to observed data. Over predictions in the highest percentiles likely reflect lack of monitoring data during high flows.
SWAT Model Calibration: Landscape Analysis, Plant Growth

Seasonal biomass growth pattern considered reasonable by a local agronomist
## SWAT Model Calibration: Landscape Analysis, Total P by Soil Hydrologic Group

<table>
<thead>
<tr>
<th>Soil Hydrologic Group</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
</tr>
</thead>
<tbody>
<tr>
<td>Apple</td>
<td>1.24</td>
<td>1.33</td>
<td>1.53</td>
<td>1.48</td>
</tr>
<tr>
<td>Barren</td>
<td>0.34</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>Urban</td>
<td>0.13</td>
<td>0.15</td>
<td>0.28</td>
<td>0.57</td>
</tr>
<tr>
<td>Corn</td>
<td>NA</td>
<td>NA</td>
<td>10.31</td>
<td>NA</td>
</tr>
<tr>
<td>Forest Deciduous</td>
<td>0.09</td>
<td>0.09</td>
<td>0.11</td>
<td>0.06</td>
</tr>
<tr>
<td>Forest Generic</td>
<td>0.09</td>
<td>0.09</td>
<td>0.13</td>
<td>NA</td>
</tr>
<tr>
<td>Lima</td>
<td>NA</td>
<td>NA</td>
<td>8.21</td>
<td>NA</td>
</tr>
<tr>
<td>Pasture</td>
<td>0.09</td>
<td>0.10</td>
<td>0.13</td>
<td>0.06</td>
</tr>
<tr>
<td>Potatoes</td>
<td>2.01</td>
<td>4.27</td>
<td>6.26</td>
<td>1.57</td>
</tr>
<tr>
<td>Range Brush</td>
<td>0.11</td>
<td>0.10</td>
<td>0.16</td>
<td>NA</td>
</tr>
<tr>
<td>Range Grass</td>
<td>0.11</td>
<td>0.12</td>
<td>0.18</td>
<td>NA</td>
</tr>
<tr>
<td>Wetlands</td>
<td>0.09</td>
<td>0.10</td>
<td>0.13</td>
<td>0.11</td>
</tr>
<tr>
<td>Winter Wheat</td>
<td>0.79</td>
<td>1.79</td>
<td>2.66</td>
<td>0.80</td>
</tr>
</tbody>
</table>

- Forest and wetlands generate lowest total P loads from urban areas higher than undeveloped.
- Highest loads from heavily cultivated agriculture (corn, lima, potato).
- P load generally increases from A to C soils.
- D soils, a very small fraction of the watershed (0.5%) did not follow expected trend.
SWAT-BATHTUB Coupling: BATHTUB Background

Steady-state model

A combination of mechanistic and empirical sub-models

Empirical equations based on 2.5 million observations from 271 lakes

Model outputs include:
- Total phosphorus
- Total nitrogen
- Chl-A
- Transparency
- Hypolimnetic oxygen demand
SWAT-BATHTUB Coupling: BATHTUB Results

BATHTUB simulation for Lake Prespa run with 2013-2014 SWAT P load as input

Model calibrated to 2014 monitoring data

Results showed Total P, Chl-A, and Secchi depth observations within range of simulation.
Corn and lima beans contribute highest total loads, followed by winter wheat potato, and apples.
10% of watershed area produces 64% of the phosphorus loads to the lake.
Alternative Management Practices

Alternative management practices currently being considered include:

• Reduced irrigation in orchards
• Fertilizer best practices (placement and rate)
• Apple orchard waste management
• Wetland restoration (point source and non point source P)
• Erosion control from agricultural land

Current SWAT Code: Irrigation depth capped to field capacity when using outside source, resulting in lower than intended irrigation amount.

Revised SWAT Code: Set to use allow user-specified depth (regardless of field capacity), resulting in intended irrigation amount.

Code change impacted overall nutrient flux.

Surface runoff from irrigation events currently a user-defined fraction of irrigation, not based on a mechanistic or empirical model.
Alternative Management Practices: Orchard Irrigation Reduction

Current Irrigation Practice: 864 mm/year, simulated as manual irrigation in SWAT

Based on a UNDP soil sampling, recommendation is to apply either 318 mm (drip) to 454 mm (surface) of irrigation, simulated as auto-irrigation in SWAT

Based on a 30-year simulation under alternative practice:
- Average irrigation of 369 mm/yr
- Water use reduced by 57%
- Total annual P reduced by 26%
- Simulated biomass growth increased, potentially due to greater nutrient availability in the soil profile
Conclusions and Next Steps

A coupled SWAT-BATHTUB model for the Prespa Lake watershed was able to simulate the hydrology and water quality of tributary rivers and the lake.

Preliminary results suggest that 10% of the landscape contributes 64% of the total P, indicating high potential for meaningful P reduction with targeted alternative practices.

Initial evaluation of improved irrigation practices showed benefits in terms of water use savings and lower pollutant losses, with no effect on crop yield.

Early estimates suggest that a reduction of total P load of ~40% would bring lake conditions solidly into the mesotrophic range.

Additional management alternatives will be assessed in the coming months.

Through the support of the UNDP, water quality monitoring will continue throughout the watershed, providing data for future model refinements.
Thank you.

Acknowledgements:
Dimitar Sekovski, UNDP
Mary Watzin, North Carolina State University
Ordan Cukaliev and Cvetanka Popovska,
University of Ss. Cyril & Methodius

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